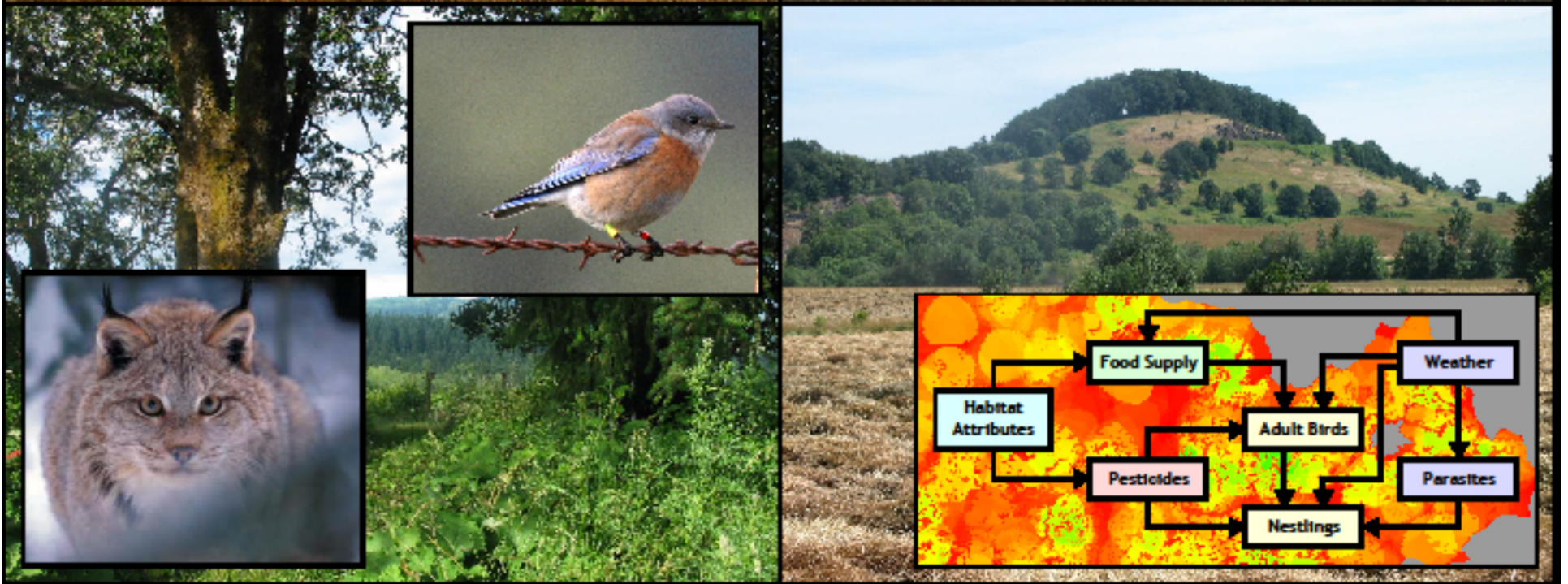


# Using HexSim to Simulate Complex Species, Landscape, and Stressor Interactions

Nathan Schumaker, Allen Brookes, Chad Wilsey  
and the Subsequent Speakers



# OOS 20 - Recent Advances in Individual-Based Population Modeling with Applications to Conservation and Management

- **Focus.** Modern simulation models and their use in conservation biology and landscape ecology.
- **Why This Focus?** Models are increasingly required to forecast plant and animal responses to future conditions and disturbance patterns.
- **Today's Talks.** This introduction, plus nine presentations illustrating a wide range of applications of the *HexSim* model.

# HexSim Past, Present, Future

- **Past.** HexSim grew out of the PATCH model. Work on PATCH dates back to 1995. HexSim development began in 2007.
- **Present.** HexSim 2.0 debuted in February 2011. Significant enhancements and corrections have since been made. Version 3.0 (in development) will include aquatic populations.
- **Future.** Case studies and outreach. Subsequent enhancements will reflect user-defined needs!

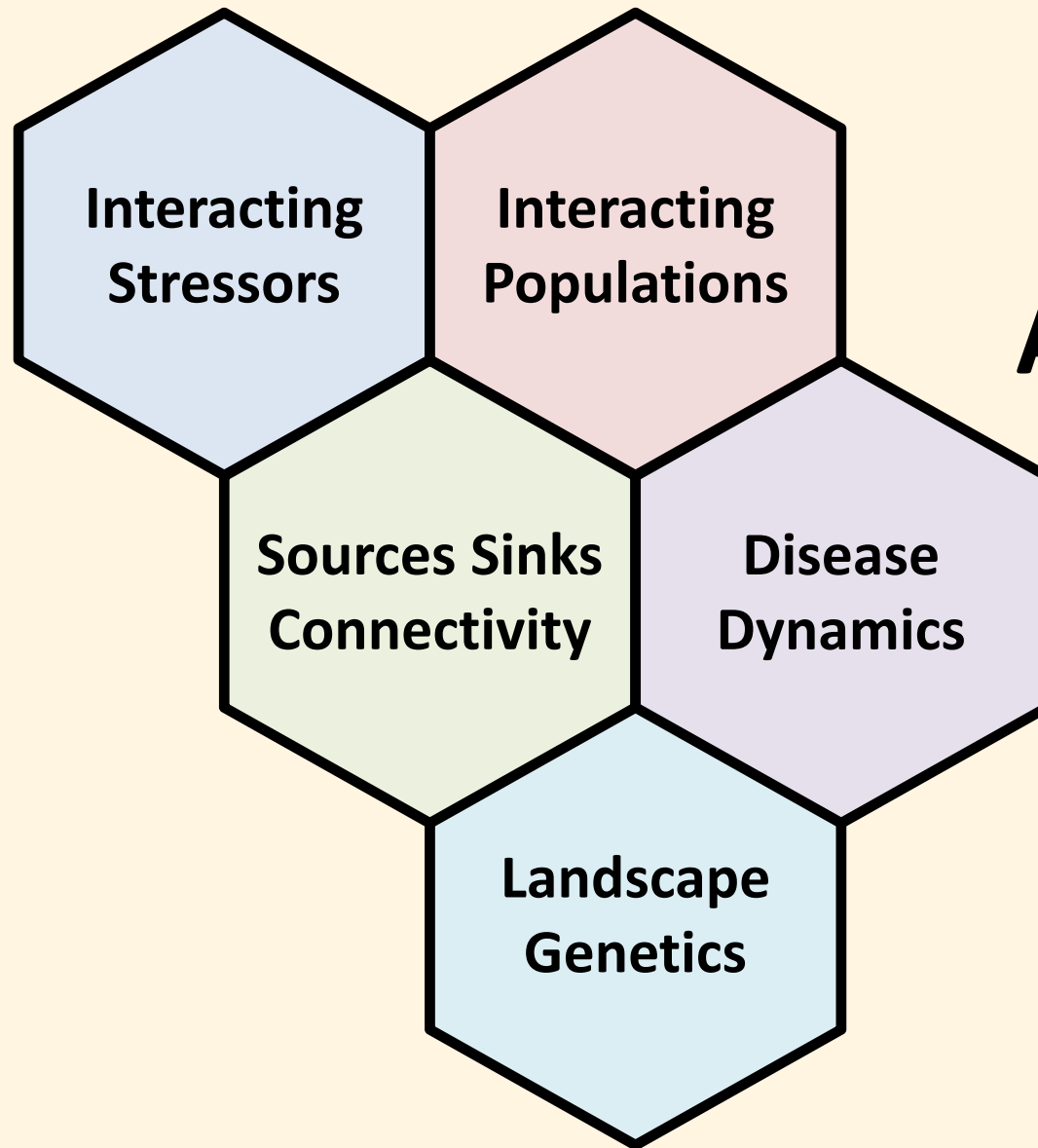
# Why HexSim ?

- It's a free, modern, and generic multi-species, multi-stressor, modeling framework.
- It's spatially-explicit, individual-based, and each individual may possess unique groups of traits.
- Simulations range from simple to complex, and can capture population and stressor interactions.

[\*\*www.hexsim.net\*\*](http://www.hexsim.net)

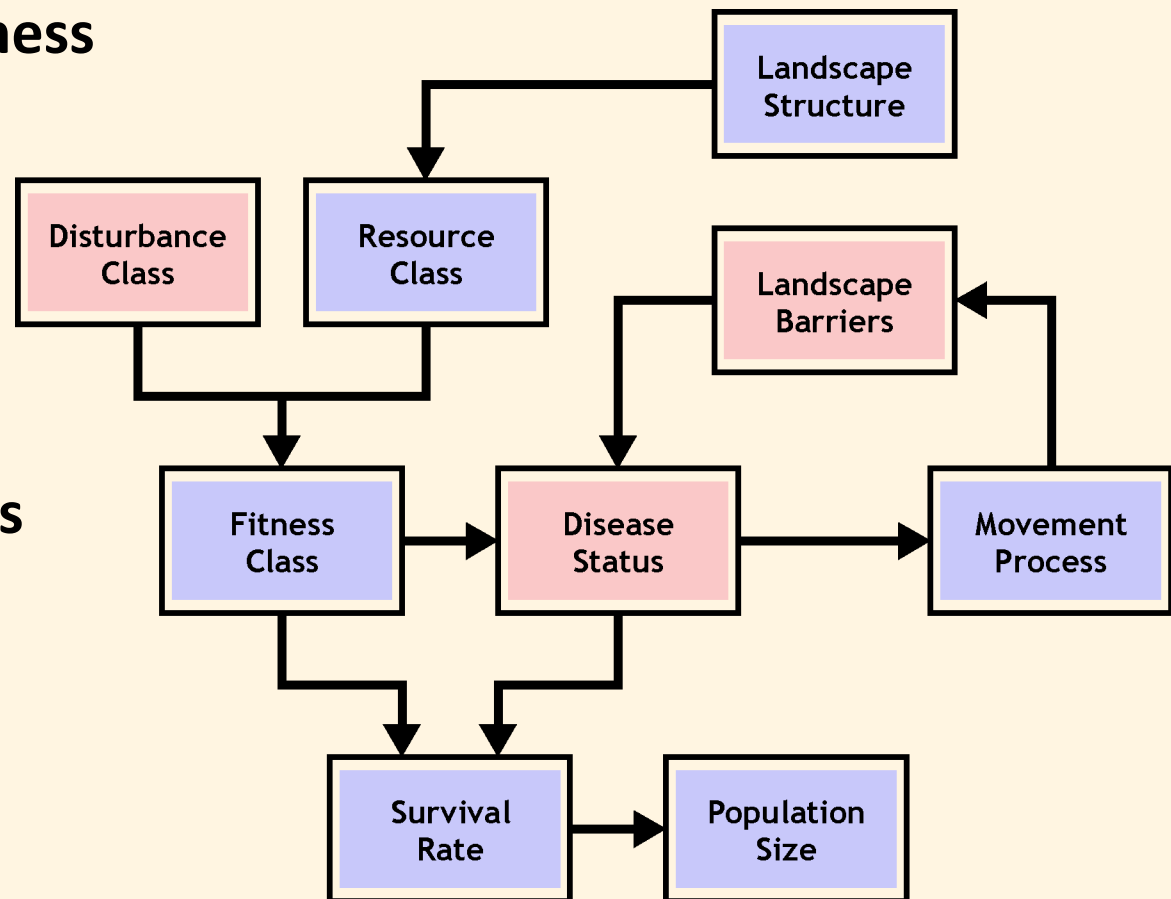


# **Five Example HexSim Applications**

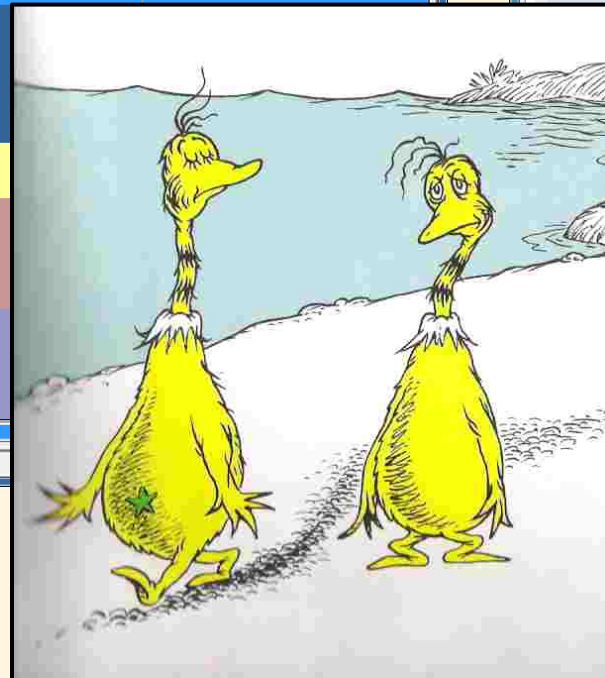
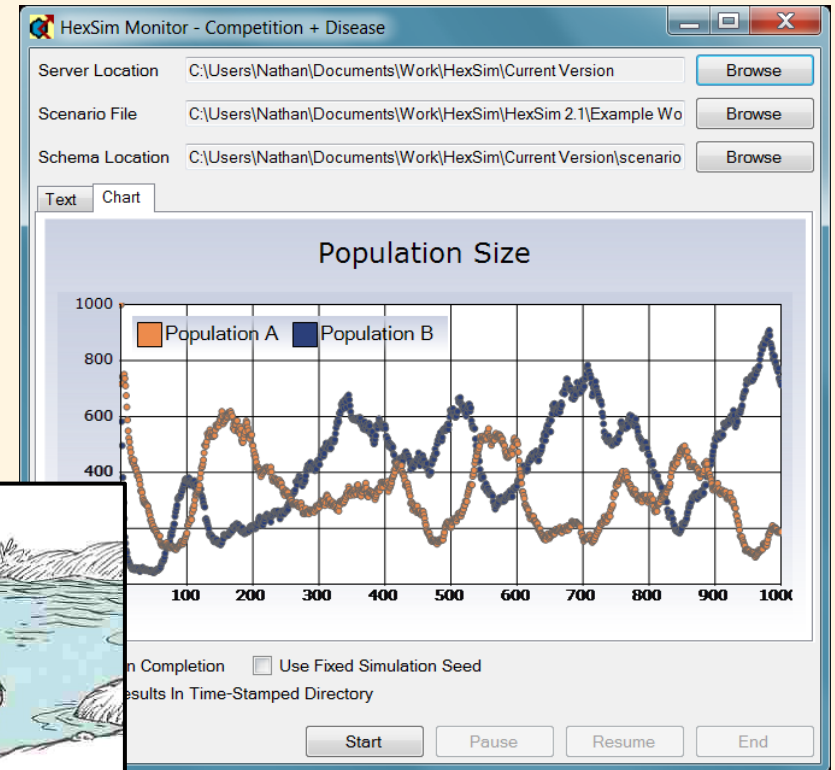
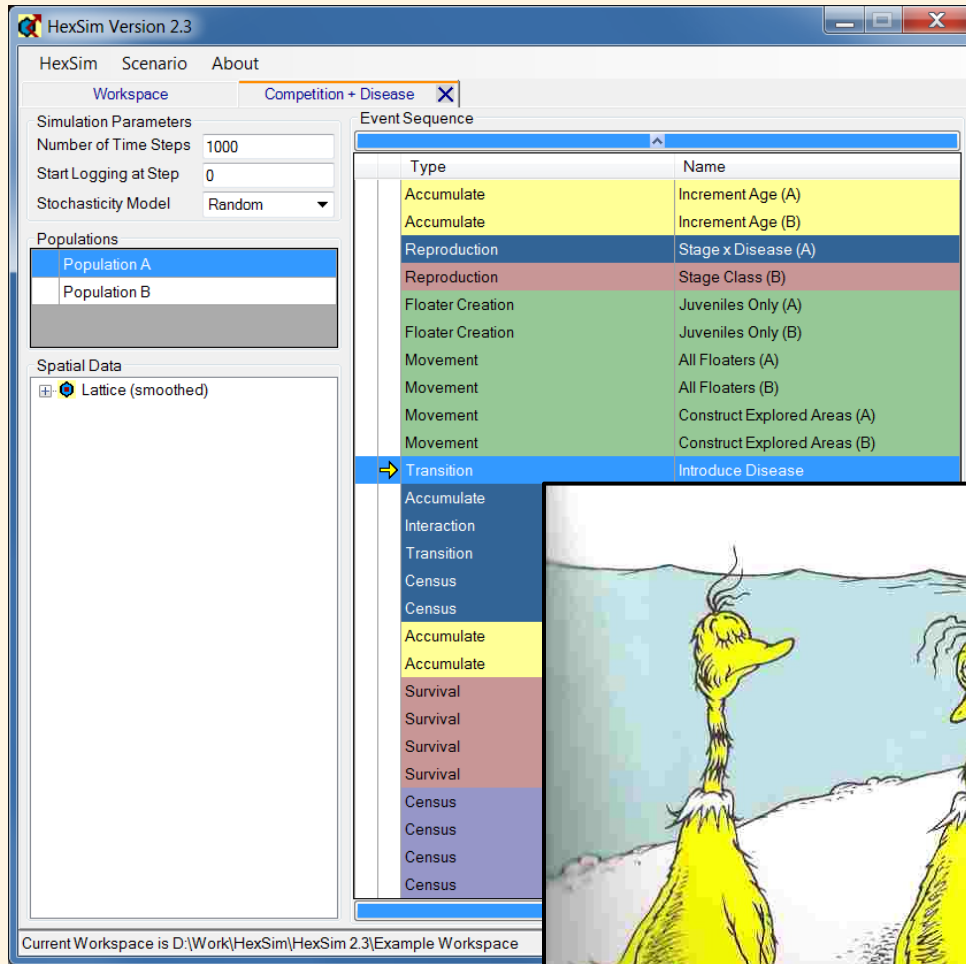


- Landscape structure and population size together limit resource acquisition
- Resource acquisition and disturbance class together control fitness
- Fitness and disease control vital rates
- Roads impact the movement process
- Movement mediates disease spread

# Interacting Stressors



# Interacting Populations



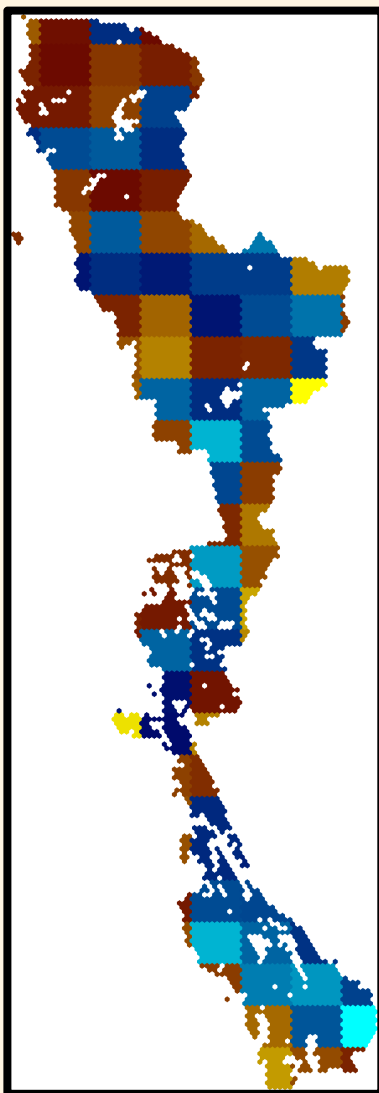
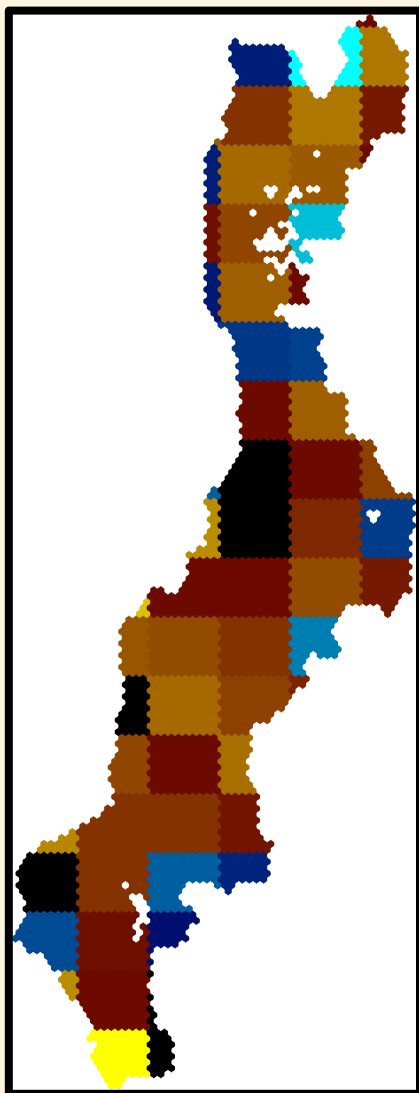
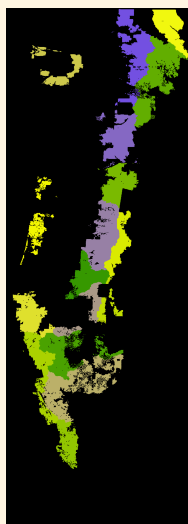
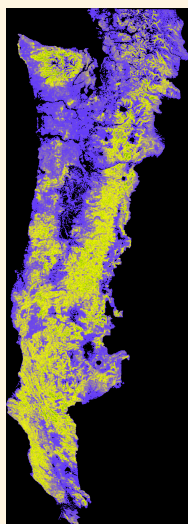
# Sources, Sinks, Connectivity

- **Multiple spatial sampling** schemes can be used simultaneously to quantify the landscape's source-sink and connectivity properties.
- The sampling schemes are completely independent of, and have absolutely **no impact on the simulated population dynamics**.
- The source-sink and connectivity metrics that result **factor in species and stressor interactions**, the effects of movement barriers, etc.

## Example from US FWS Spotted Owl Model

Deschutes NF

Six Rivers NF



# Sources and Sinks in HexSim

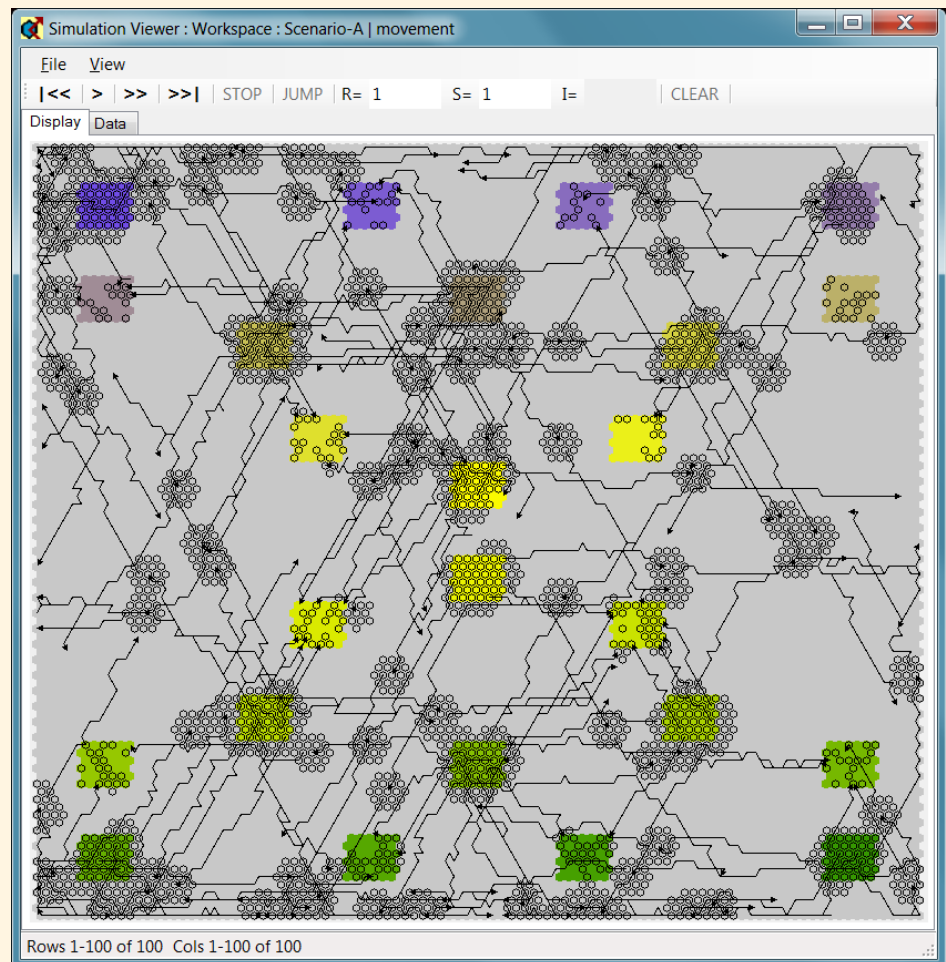
National Forest	Type	Percent of Worst Sink Or Best Source
Deschutes	Sink	100.0
Winema	Sink	44.8
Siuslaw	Sink	5.5
Okanogan	Sink	1.7
Olympic	Sink	0.4
Mount Baker	Source	0.1
Gifford-Pinchot	Source	3.1
Wenatchee	Source	9.0
Mount Hood	Source	17.4
Siskiyou	Source	18.3
Willamette	Source	42.0
Mendocino	Source	42.2
Klamath	Source	42.9
Rogue River	Source	56.6
Shasta-Trinity	Source	66.4
Umpqua	Source	69.3
Six Rivers	Source	100.0



# Connectivity in HexSim

For each sampling scheme, HexSim will:

- Track the flux of individuals moving between locations, incorporating survival and reproduction into the rates
- Construct a projection matrix that can also be used to estimate  $\lambda$
- Does not record paths used to move between locations (but see Carroll / CAT talk)



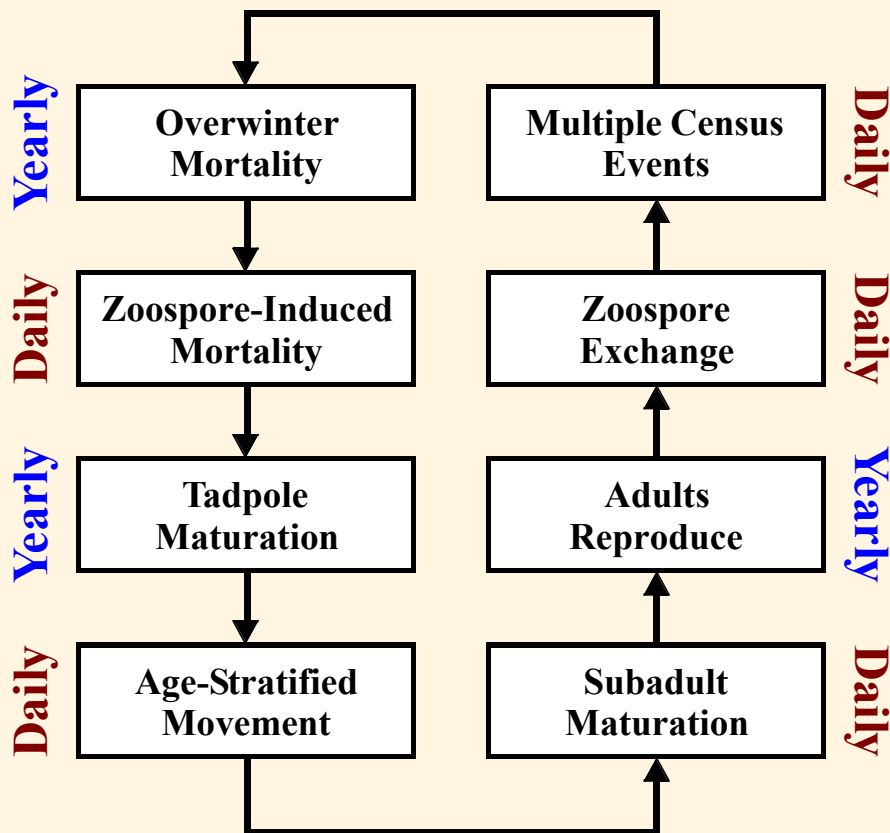
# National Forest Connectivity

## Example from US FWS Spotted Owl Model

	Mount Baker	Gifford Pinchot	Willamette	Rogue River	Shasta-Trinity	Olympic	Siskiyou	Okanogan	Suslaw	Deschutes	Winema	Six Rivers	Mendocino	Mount Hood	Wenatchee	Klamath	Umpqua
Mount Baker	0.9110	0.0001	--	--	--	--	--	0.0083	--	--	--	--	--	--	0.0153	--	--
Gifford Pinchot	0.0004	0.9461	--	--	--	--	--	--	--	--	--	--	--	0.0016	0.0056	--	--
Willamette	--	--	0.9501	0.0000	--	--	--	--	0.0001	0.0381	--	--	--	0.0190	--	--	0.0176
Rogue River	--	--	0.0000	0.8532	--	--	0.0087	--	--	0.0000	0.0560	--	--	--	--	0.0175	0.0199
Shasta-Trinity	--	--	--	0.0000	0.9157	--	--	--	--	--	--	0.0325	0.0130	--	--	0.0115	--
Olympic	--	--	--	--	--	0.7083	--	--	--	--	--	--	--	--	--	--	--
Siskiyou	--	--	--	0.0066	--	--	0.9122	--	--	--	--	0.0026	--	--	--	0.0046	--
Okanogan	0.0001	--	--	--	--	--	--	0.8738	--	--	--	--	--	--	0.0002	--	--
Suslaw	--	--	0.0000	--	--	--	0.0000	--	0.8692	--	--	--	--	0.0000	--	--	--
Deschutes	--	--	0.0052	0.0001	--	--	--	--	--	0.8989	--	--	--	0.0000	--	--	0.0005
Winema	--	--	--	0.0158	--	--	--	--	--	0.0000	0.8823	--	--	--	--	0.0000	0.0000
Six Rivers	--	--	--	0.0000	0.0234	--	0.0060	--	--	--	--	0.9000	0.0082	--	--	0.0276	--
Mendocino	--	--	--	--	0.0062	--	--	--	--	--	--	0.0042	0.9420	--	--	--	--
Mount Hood	--	0.0023	0.0059	--	--	--	--	--	--	0.0001	--	--	--	0.9487	--	--	--
Wenatchee	0.0399	0.0041	--	--	--	--	--	0.0094	--	--	--	--	--	--	0.9441	--	--
Klamath	--	--	--	0.0269	0.0063	--	0.0090	--	--	--	0.0001	0.0214	--	--	--	0.9011	--
Umpqua	--	--	0.0230	0.0309	--	--	--	--	--	0.0074	0.0001	--	--	--	--	--	0.9252

# Disease Dynamics

## Environmentally-Mediated Transmission



## Direct Transmission

Competition + Disease | Transition ( Disease Progression )

Name: Disease Progression

Properties | Transitions | Description

Transition To ⇒ Combinations ↓	Susceptible	Infected	Sick	Recovered
▶ Susceptible, Unexposed	1	0	0	0
Susceptible, Exposed	0	1	0	0
Infected, Unexposed	0	0.5	0.5	0
Infected, Exposed	0	0.5	0.5	0
Sick, Unexposed	0	0	0.8	0.2
Sick, Exposed	0	0	0.8	0.2
Recovered, Unexposed	1	0	0	0
Recovered, Exposed	1	0	0	0

< 1 of 1 > Add Delete

Recover Close

# Landscape Genetics in HexSim

The screenshot displays the HexSim Version 2.3 interface. The main workspace is titled "Genetics\_Model" and shows a list of simulation parameters and populations. The "Populations" section lists "Spotted Owls". The "Spatial Data" section lists "Demographic Study Areas", "MaxEnt 2006 NSO Habitat", "Modeling Regions", and "Physiographic Provinces".

Overlaid on the main window are several dialog boxes:

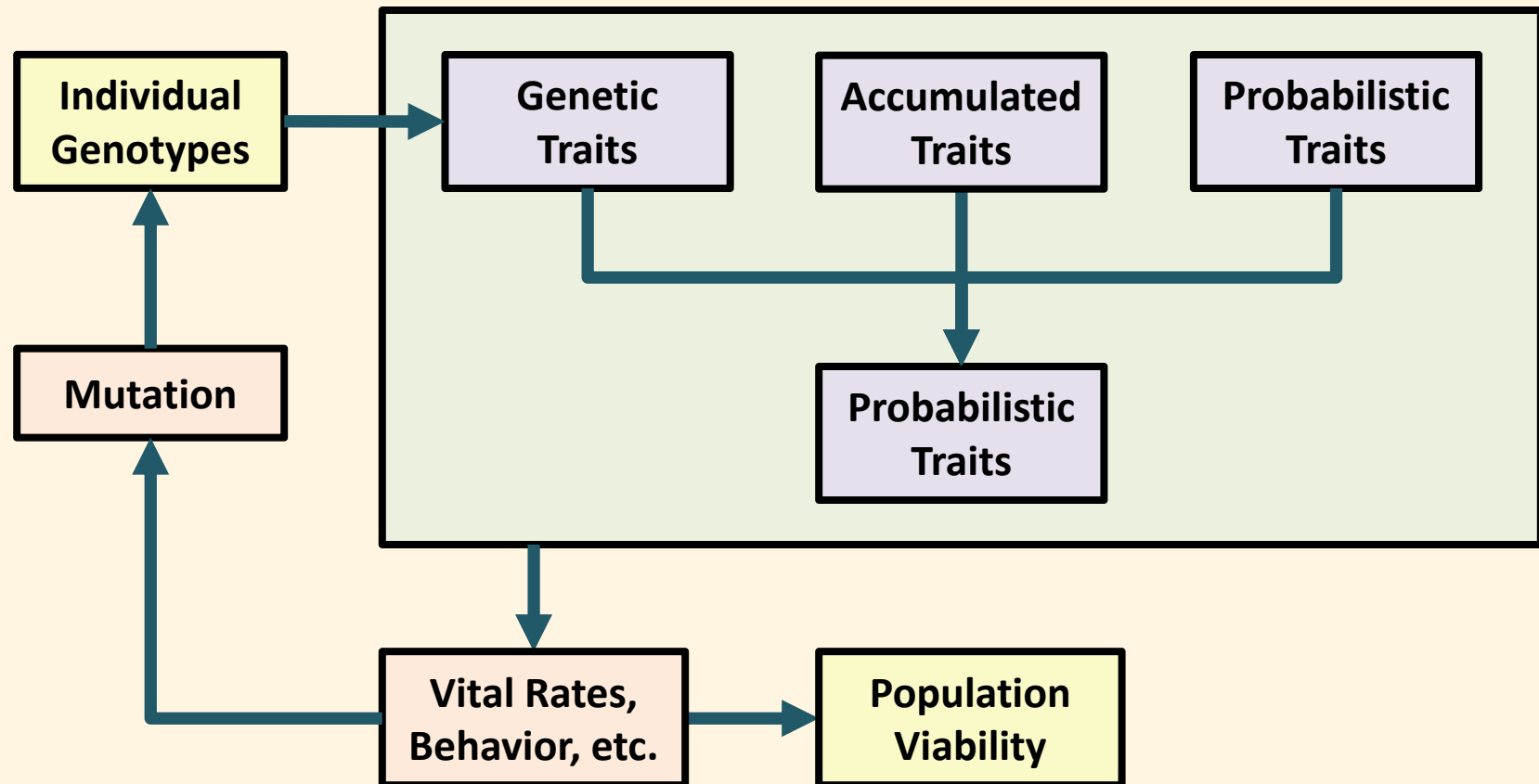
- Locus Data** (multiple instances): These dialog boxes allow configuring individual loci. The "Name" field is set to "Locus A", "Locus B", and "Locus C". The "Number of Alleles" is set to 2. The "Inheritance Type" is set to "Autosomal". The "Initial Allele Frequency" is set to "0.5".
- Genetics\_Model | Interaction (Form Pairs)**: This dialog box allows configuring interactions between populations. The "Name" field is set to "Form Pairs". The "Properties" tab is selected, showing the "Primary Population" as "Spotted Owls" and the "Zone of Influence" as "Allocated". The "Influence Rule" is set to "Always". The "Spatial Data" section is set to ">>> None Selected <".

The "Interaction (Form Pairs)" dialog box also includes a table for defining interaction rules:

Primary → Secondary ↓	Female, Floater	Female, Territory Holder	Male, Floater	Male, Territory Holder
Female, Floater				
Female, Territory				
Male, Floater				
Male, Territory		# 1 is 100.0 %		

The "Current Workspace is D:\Work\Research\Spotted Owls\Workspace" is displayed at the bottom.

# Works With Both Neutral and Adaptive Alleles





Interacting  
Populations

Interacting  
Stressors

# Speaker: Peter Singleton

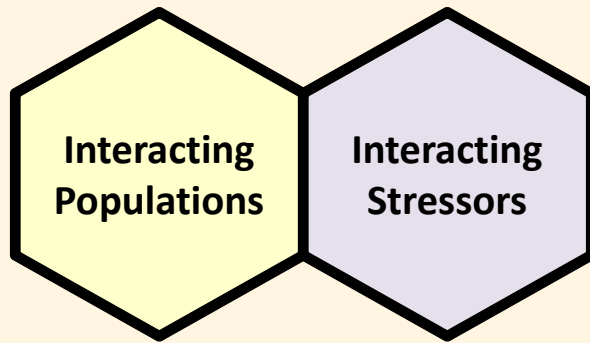
## Spotted Owl – Barred Owl Competition



**Spotted Owl**

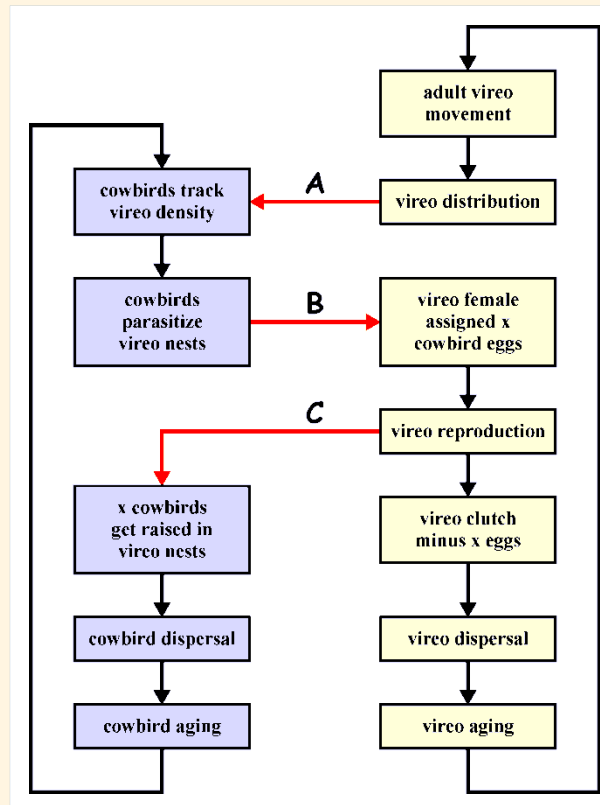


**Barred Owl**



# Speaker: Chad Wilsey

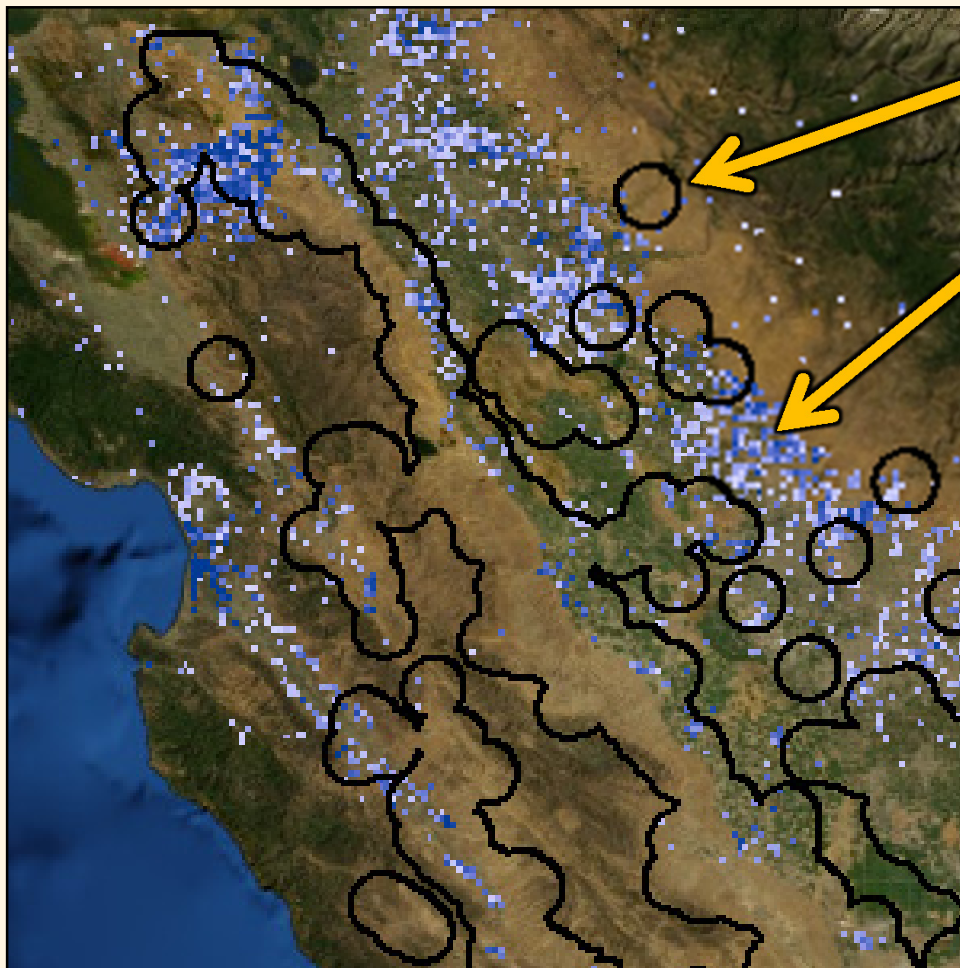
## Black-capped Vireo – Cowbird Interactions



Interacting  
Stressors

# Speaker: Theresa Nogeire

## Kit Fox Responses to Multiple Stressors



Kit Fox Range

Rodenticides





Sources Sinks  
Connectivity

# Speaker: Carlos Carroll

## The Connectivity Analysis Toolkit (CAT)

Connectivity Analysis Toolkit

Help About

HexMaps Graphs Connectivity Output

Function [Beta] Maximum Flow

Graph File Browse

Input File(s) Type Generic Data

Input File Browse

( Unused ) Browse

Maximum Distance 0.0000

Output File Browse

☐ Use Scaling

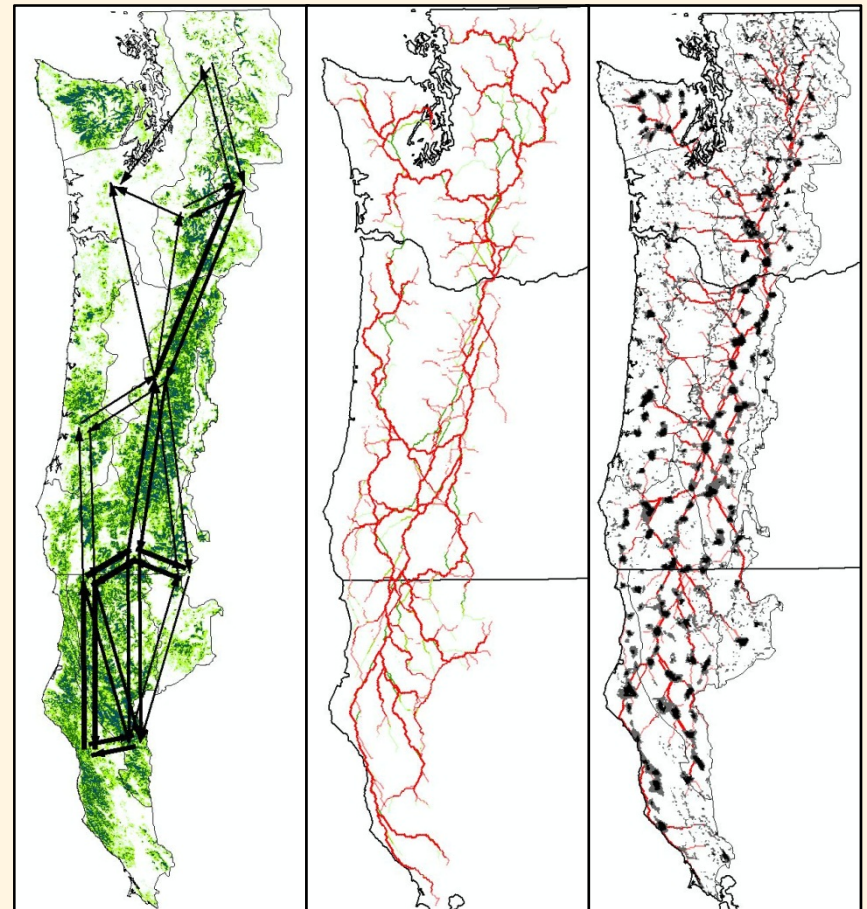
☐ No Data Value -9999

Number of Threads 8

Supply Fraction 1.0000

Probability 0.8500

Run

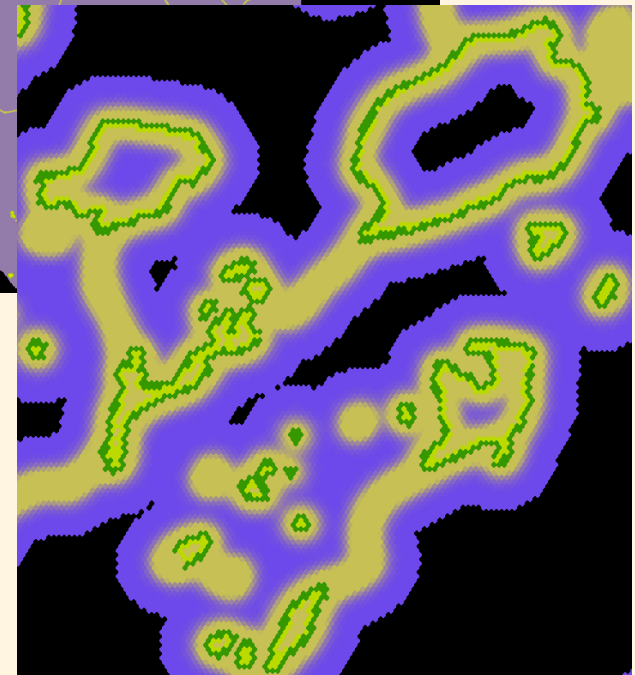
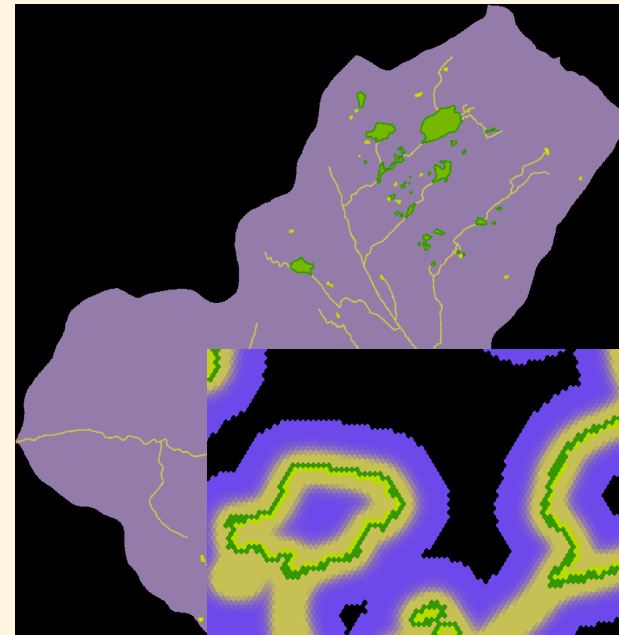
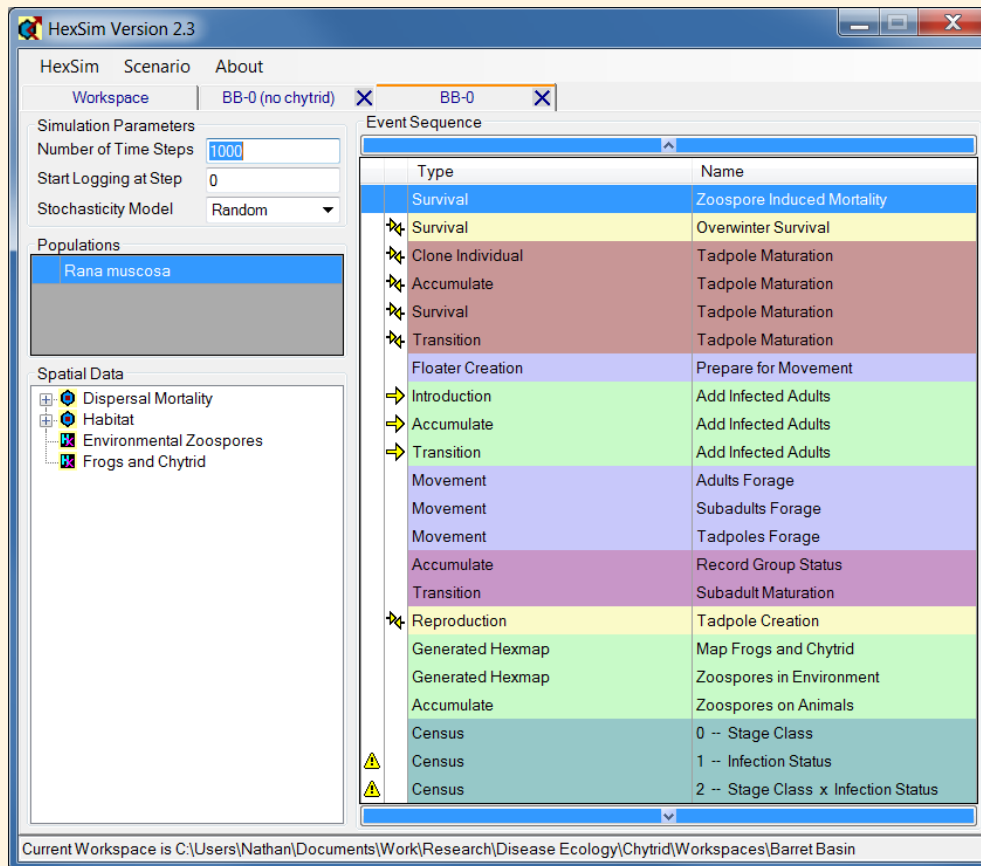


Interacting  
Stressors

Disease  
Dynamics

# Speaker: Gisselle Yang Xie

## Mountain Yellow-Legged Frogs and the Chytrid Fungus





Interacting  
Stressors

# Speaker: Michael Tuma

## Desert Tortoise Population Dynamics

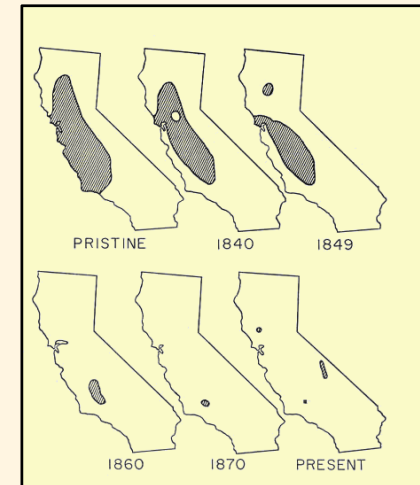
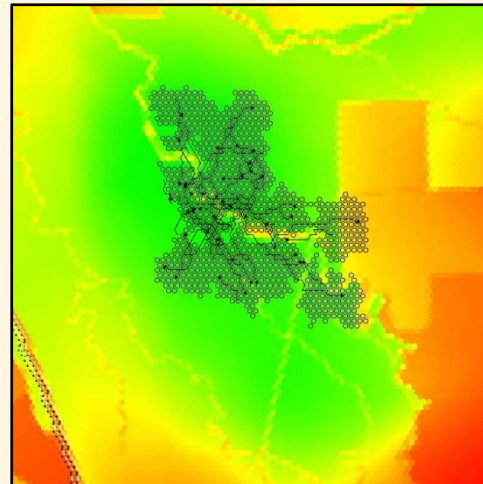


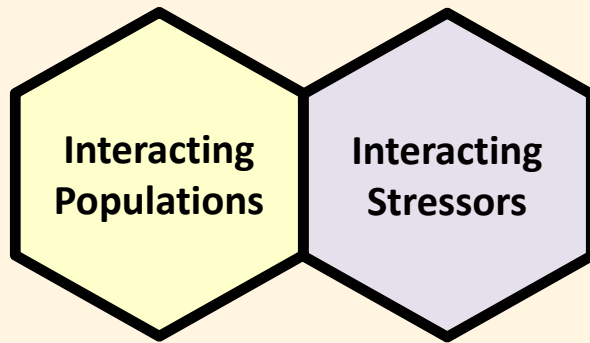
©2010 Jack the Lizard

Interacting  
Stressors

# Speaker: Patrick Huber

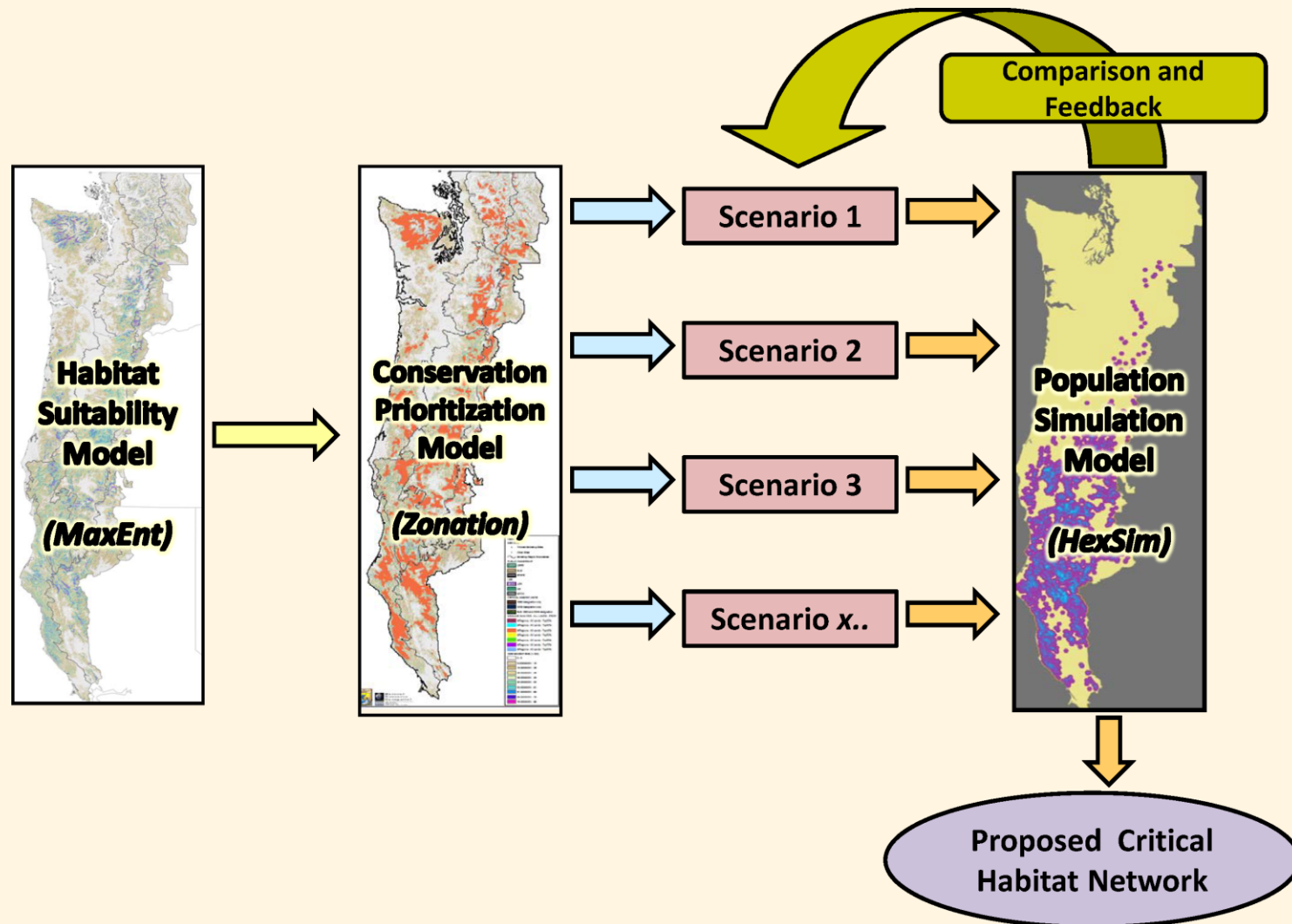
## Tule Elk Reintroduction Strategies





# Speaker: Jeffrey Dunk

## Spotted Owl Conservation

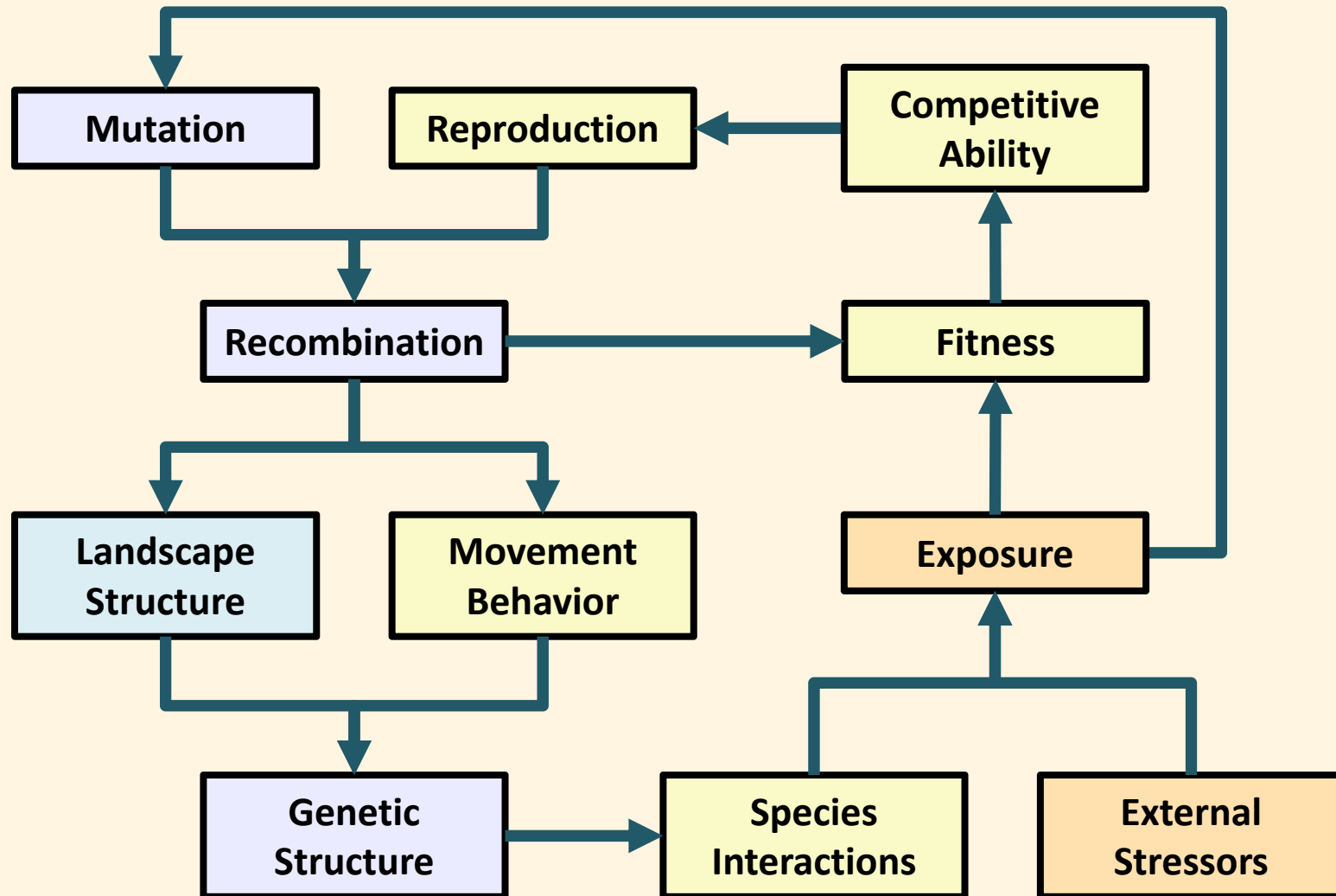




Landscape  
Genetics

# Speaker: Jennifer Day

## Adding Realism to Landscape Genetics



# Acknowledgements

- **Kevin Djang** developed the HexSim model GUI. **Josh Lawler** contributed to all aspects of HexSim.
- **Carlos Carroll, Chris Jordan, and David Olszyk** provided invaluable support at key times.
- The **US EPA** supported Schumaker, Brookes, and Djang. **SERDP (grant number SI-1541)** supported Brookes, and Lawler.
- We are indebted to many users who happily documented HexSim's (previous) shortcomings!